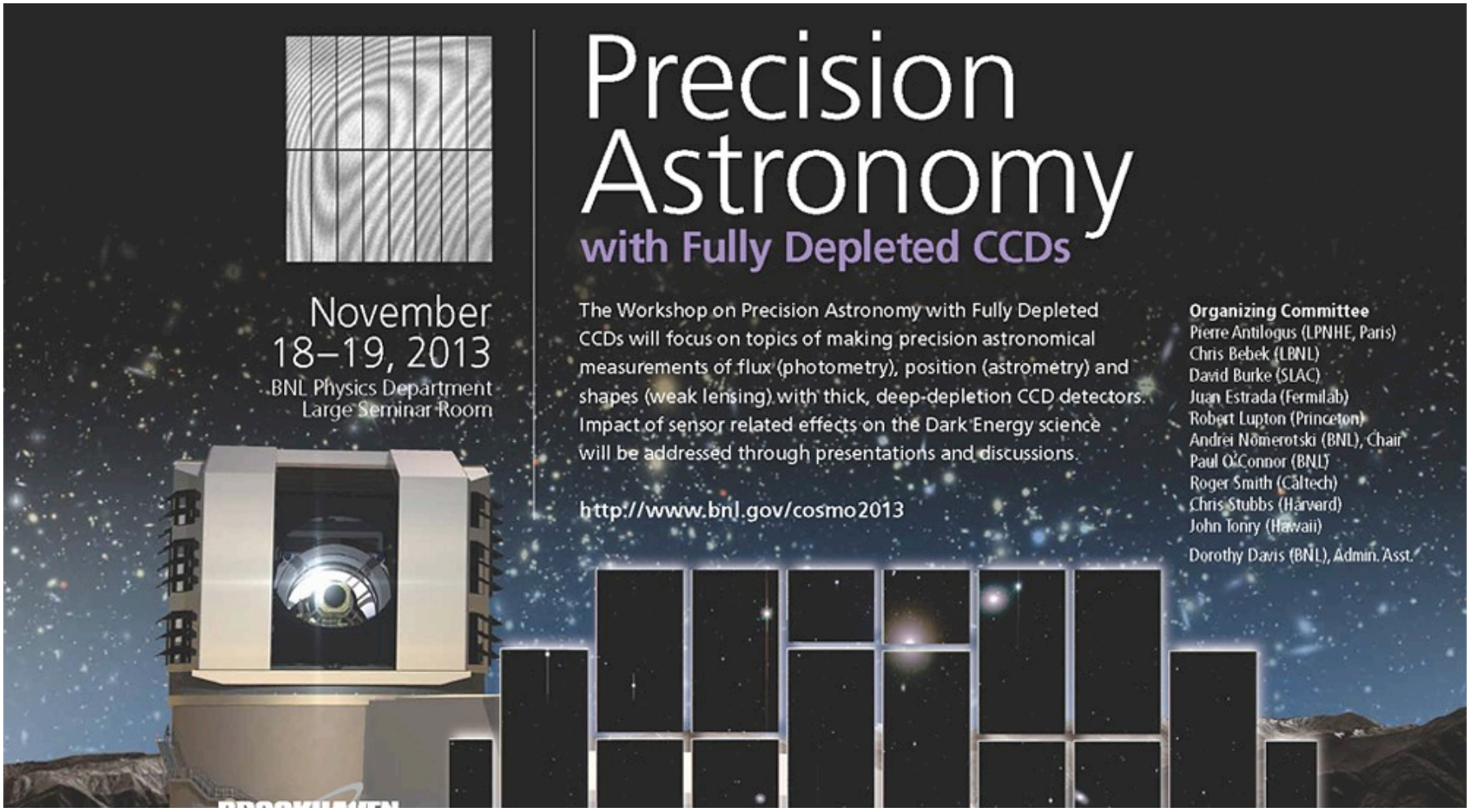
Workshop Summary: Precision Astronomy with Fully Depleted CCDs

Andrei Nomerotski (BNL)

DESC collaboration meeting, Pittsburgh, 6 December 2013



Workshop Goals

- Bring together people working on instruments, algorithms and science
- Bring together current and future experiments

NOT yet another sensor conference!

- Chris Stubbs in Introduction :

  [We need to] Identify next steps in the blended process of calibration, operation, data reduction and exploitation of data from deep depletion CCDs,

  in support of measurements at higher precision.

- Over 70 participants from 32 institutions, 14 from outside the US
- 20 talks and 8 posters

Precision Astronomy with Fully Depleted CCDs

from Monday, November 18, 2013 at **08:00** to Tuesday, November 19, 2013 at **17:00** (US/Eastern)
at **Physics Department (Large Seminar Room)**

Description **WORKSHOP AGENDA**

The Workshop on Precision Astronomy with Fully Depleted CCDs will focus on topics of making precision astronomical measurements of flux (photometry), position (astrometry) and shapes (weak lensing) with thick, deep-depleted CCD detectors. Impact of sensor related effects on the Dark Energy science will be addressed through presentations and discussions.

Instructions for ReadyTalk remote connection

To join the audio conference:
1. Dial Toll-Free Number: 866-740-1260 (U.S. & Canada)
2. International participants dial Toll Number: 303-248-0285 or International Toll-Free Number
3. Enter the 7-digit access code, 3448338, followed by "#"

Administrative Assistant dorothyd@bnl.gov

Go to day

Monday, November 18, 2013

08:00 - 09:00 Registration *1h0'* (Physics Department, Seminar Lounge)

09:00 - 09:10 Welcome *10'*
Speaker: Berndt Mueller (Associate Laboratory Director for Nuclear & Particle Physics)
Material: **Slides**

09:05 - 09:35 Introduction *30'*
Speaker: Chris Stubbs (Harvard)
Material: **Slides**

09:35 - 10:05 Precision Astrometry and Photometry from Pan-STARRS 1 *30'*
Speaker: Gene Magnier (University of Hawaii)
Material: **Slides**

10:05 - 10:35 On-sky performance and calibration of the Dark Energy Camera *30'*
Speaker: Gary Bernstein (Penn)
Material: **Slides**

10:35 - 11:00 Coffee Break (Physics Department (Seminar Lounge))

11:00 - 11:30 Hyper Suprime-Cam and HPK CCDs *30'*
Speaker: Satoshi Miyazaki (NAOJ)
Material: **Slides**

11:30 - 12:30 Discussion and workshop photo *1h0'*

12:30 - 13:30 Lunch (Berkner Hall (Building 488))

13:30 - 14:00 LSST sensors: how will dark energy be constrained with lensed photo-conversions? *30'*
Speaker: Andy Rasmussen (SLAC)
Material: **Slides**

14:00 - 14:30 Challenges for precision shape measurements *30'*
Speaker: Michael Jarvis (Penn)
Material: **Slides**

14:30 - 15:00 PhoSim: A Code to Simulate Telescopes One Photon at a Time *30'*
Speaker: John Peterson (Purdue)
Material: **Slides**

15:00 - 15:30 Coffee Break (Physics Department (Seminar Lounge))

15:30 - 16:00 Consequences of thick CCDs on Image Processing *30'*
Speaker: Robert Lupton (Princeton)
Material: **Slides**

16:00 - 16:30 Shear estimators in Weak Lensing *30'*
Speaker: Erin Sheldon (BNL)
Material: **Slides**

16:30 - 17:30 Discussion *1h0'*

17:30 - 18:30 Poster Session *1h0'*
Material: **Slides**

- Spot scan probe of edge and midline effects in fully-depleted CCDs *15'*
  Speaker: Paul O'Connor (BNL)
  Material: **Poster**
- STEP mission: High precision Space Astrometry *15'*
  Speaker: Ding Chen (Center for Space Science and Applied Research, Chinese Academy of Sciences)
  Material: **Slides**
- X-ray Analysis of Fully Depleted Thick CCDs with Small Pixel Size *15'*
  Speaker: Ivan Kotov (BNL)
  Material: **Slides**
- The GREAT3 Challenge *15'*
  Speaker: Hironao Miyatake (Princeton)
  Material: **Slides**
- Impact of Chromatic Effects on Measurements of Galaxy Position, Shape and Flux *15'*
  Speaker: Joshua Meyers (SLAC)
  Material: **Slides**
- PAU: A Fully Depleted Mosaic Imager with Narrow Band Filters *15'*
  Speaker: Santiago Serrano (Instituto de Ciencias del Espacio, Barcelona)
  Material: **Slides**
- DECal Calibration System *15'*
  Speaker: William Wester (Fermilab)
  Material: **Slides**
- MegaPipe astrometry for the New Horizons spacecraft *15'*
  Speaker: Stephen Gwyn (Canadian Astronomy Data Centre)
  Material: **Slides**

19:00 - 22:00 Workshop Dinner (Blackwells, Wading River)
www.blackwellsrestaurant.com/index.html

Tuesday, November 19, 2013

09:00 - 09:20 Emulating Weak Gravitational Lensing Measurements in the Lab *20'*
Speaker: Chaz Shapiro (JPL)

Material: Slides

09:20 - 09:40 Using a Fast Beam (f/1.2) to Characterize Thick CCD's *20'*
Speaker: Kirk Gilmore (SLAC)
Material: Slides

09:40 - 10:00 Tree rings and other sensor effects in Dark Energy Camera *20'*
Speaker: Andres Plazas Malagon (BNL)
Material: Slides

10:00 - 10:30 Coffee Break (Physics Department (Seminar Lounge))

10:30 - 11:00 The brighter-fatter effect and pixel correlations *30'*
Speaker: Pierre Astier (LPNHE, Paris)
Material: Slides

11:00 - 11:30 Testing the Shrinking Pixel Hypothesis *30'*
Speaker: Roger Smith (Caltech)
Material: Slides

11:30 - 12:20 Discussion *50'*

12:20 - 13:30 Lunch (Berkner Hall (Building 488))

13:30 - 14:00 Fully Depleted Imager Technology at MIT Lincoln Laboratory *30'*
Speaker: Vyshi Suntharalingam (Lincoln Lab)
Material: Slides Video

14:00 - 14:30 Physics of depleted CCDs *30'*
Speaker: Steve Holland (LBNL)
Material: Slides

14:30 - 15:00 Dark Matter searches with fully depleted CCDs *30'*
Speaker: Juan Estrada (Fermilab)
Material: Slides

15:00 - 15:30 Spectral extraction of BOSS fully-depleted CCD data *30'*
Speaker: Julien Guy (LBNL)
Material: Slides

15:30 - 16:00 Coffee Break (Physics Department (Seminar Lounge))

16:00 - 16:40 Summary *40'*
Speaker: Jim Gunn (Princeton)
Material: Slides

16:40 - 16:50 Concluding Remarks *10'*

Workshop Web Site

http://www.bnl.gov/cosmo2013/index.php

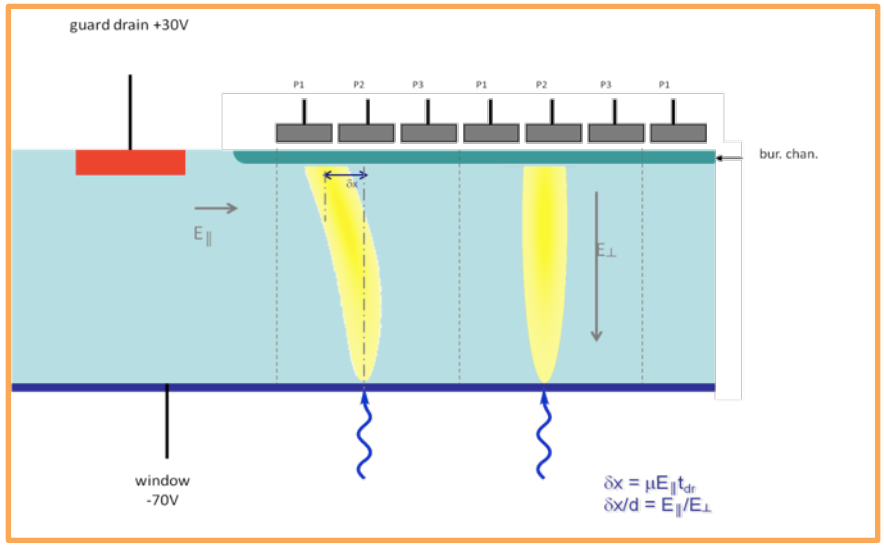
All talks and posters are linked to the agenda:

https://indico.bnl.gov/conferenceDisplay.py?confId=672

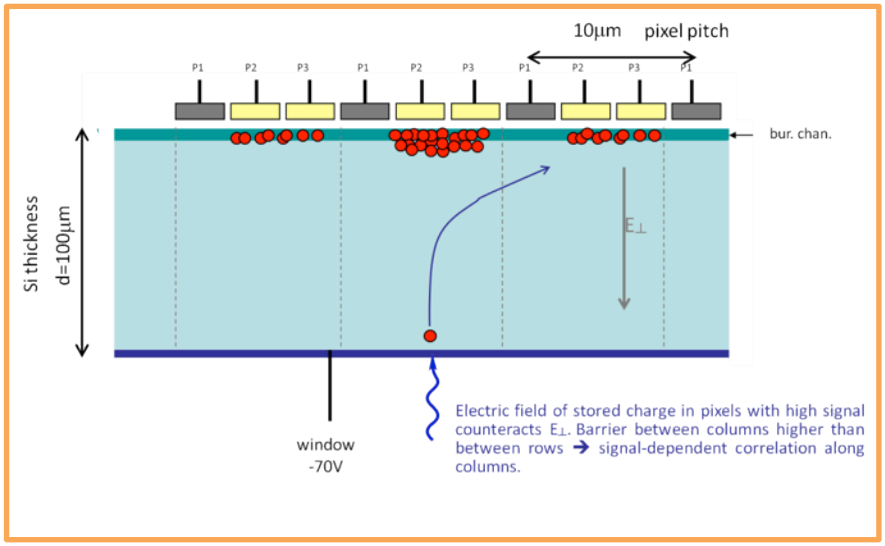
What's the problem with thick CCDs?

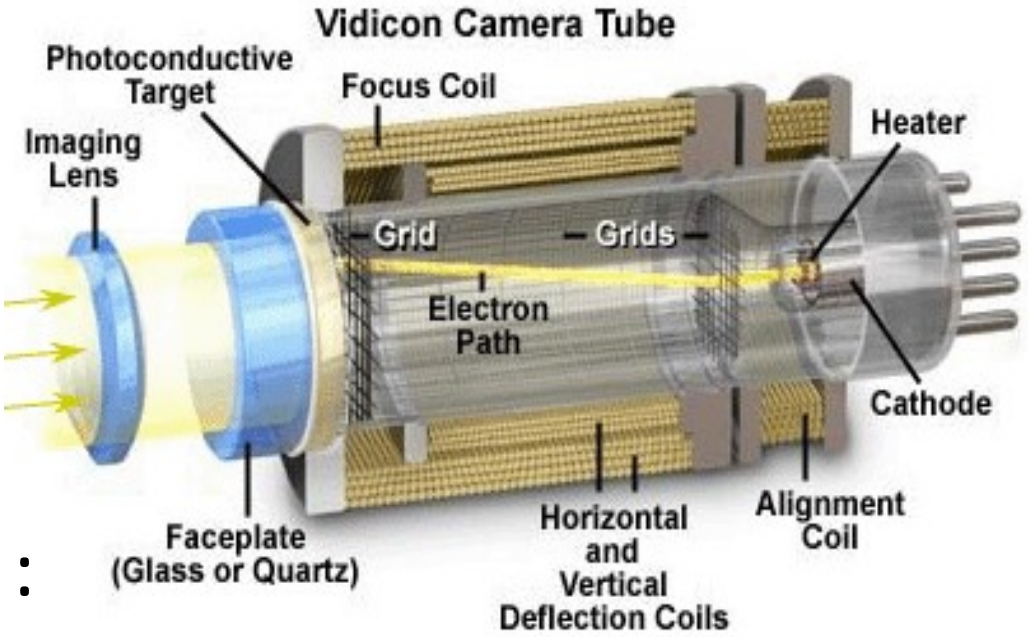
Electric field lines inside CCD are not straight → pixels change their size and shape

Static : edge effects, tree-rings



"Dynamic" : brighter-fatter effect



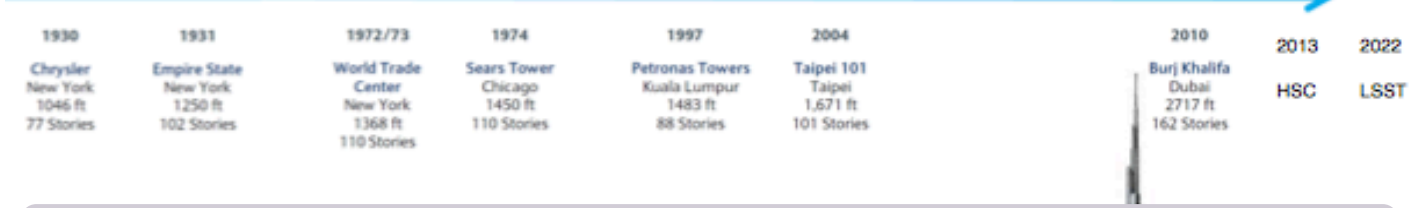


Jim Gunn in Summary :

We were so happy when CCDs came along: High QE, no more electron optics --!!-- but we were wrong

.....

So we all need to get out our copies of Jackson and dig in



Consequences of thick CCDs on Image Processing

Robert Lupton

Princeton University

2013-11-18

Pixels are bendable skyscrapers

It was the right moment to organize the workshop – several experiments started to take data

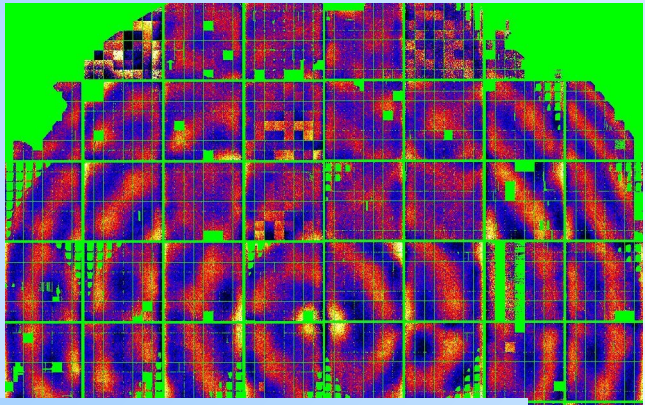
Gene Magnier: Pan-STARRS

Summary

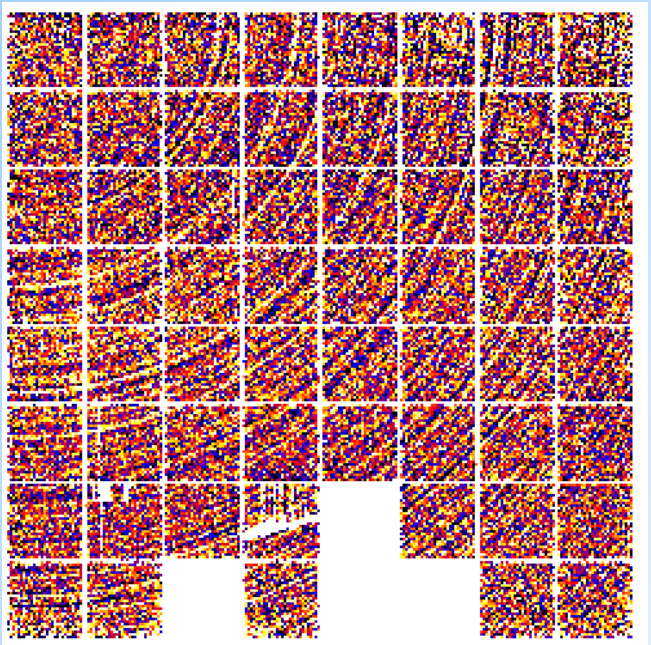
- PS1 is achieving good astrometry & photometry
- There is room for improvement
  - static systematics
  - finer spatial modeling of PSF variations
  - finer spatial modeling of astrometric corrections
  - stellar density is the ultimate limiting factor
- Tree-rings show up in astrometry and photometry
- We do not really understand the tree rings...

Astrometric Systematics

- mean residuals as a function of camera position



radial component

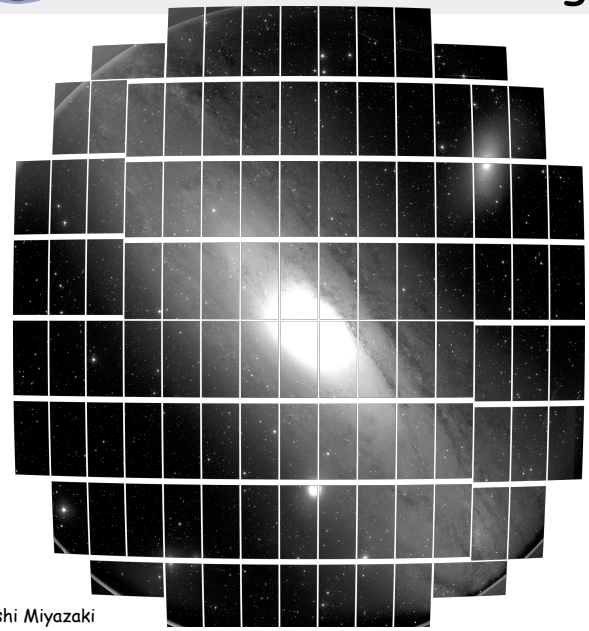


Satoshi Miyazaki : Hyper Suprime Cam

- Largest camera to date – pathfinder for LSST; 100+ CCDs, ~ 1GPix
- Currently in commissioning, 300-night survey begins next year

- So far only lab results of more subtle CCD effects

HSC M31 Image

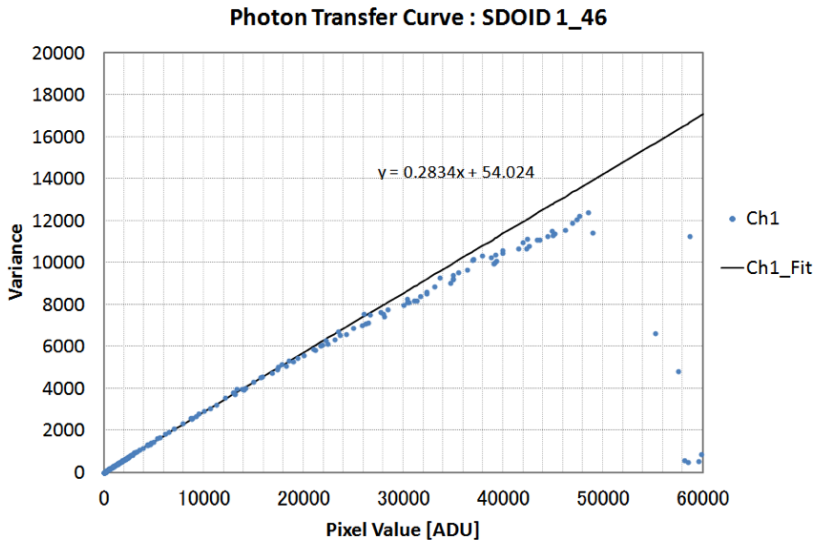


Bias Subtraction
Flat Fielding

Warp CCD images to map onto the sky

Satoshi Miyazaki HSC/NAOJ

HPK CCD Photon Transfer



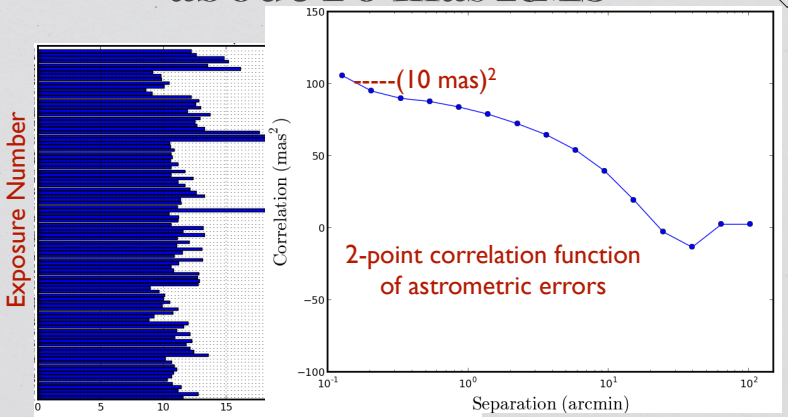
Satoshi Miyazaki HSC/NAOJ

Gary Bernstein : On sky performance and calibration of Dark Energy Camera

Highlights

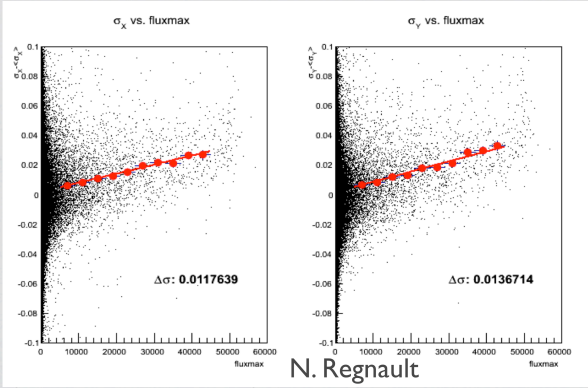
- Great devices with few "features"!
- Weak fringing, as expected from deep-depletion. Stable pattern.
- Deep-depletion CCDs more susceptible to pixel-area variations.
  - We characterize and remove 2 known patterns, mask 1.
  - Constant response is better approximation to QE than are the dome flats
  - No method available to map the small-scale 0.003-pixel astrometric shift
- With proper treatment of scattered light & pixel-size variations: Attain 1.5 mmag photometric repeatability across array (+sky estimation errors)
- Few-mmag p-p response variation over a season.
- Stellar response more stable than dome flats!
- Astrometry limited to 10 mas by probable atmospheric effects
- Brighter-fatter relation exists, likely correctable at pixel level.

Relative astrometric errors are about 10 mas RMS



From Bob Armstrong

Brighter stars are observed to have broader PSFs

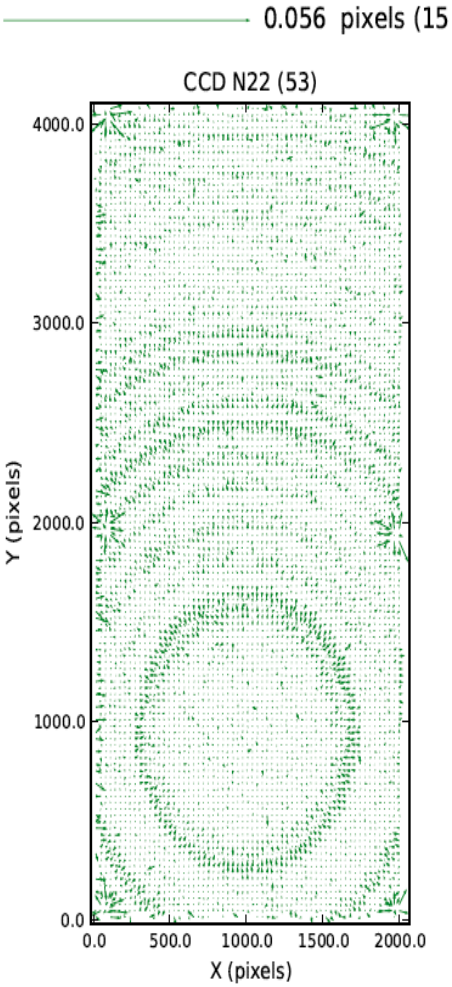


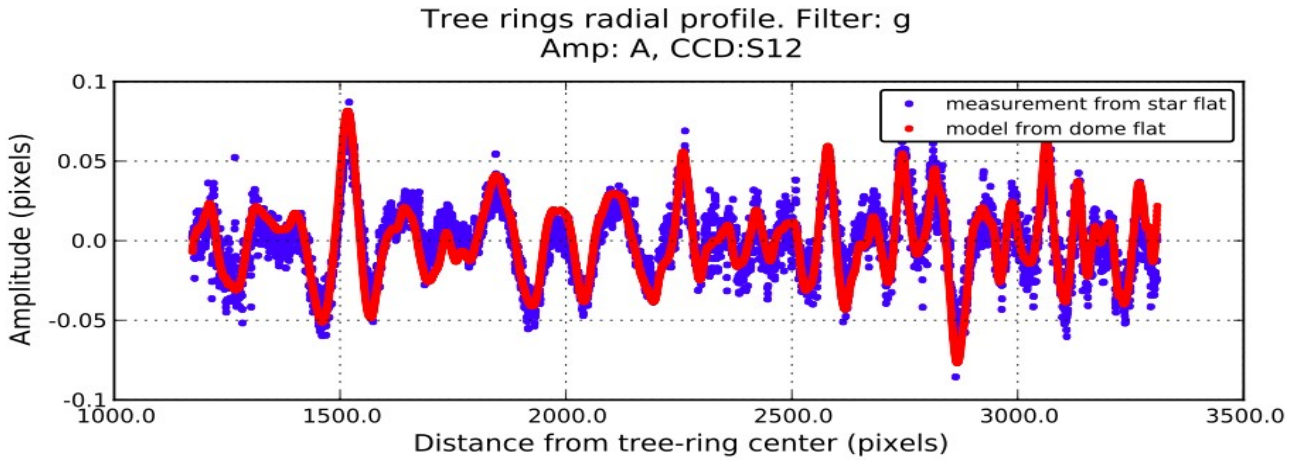
N. Regnault

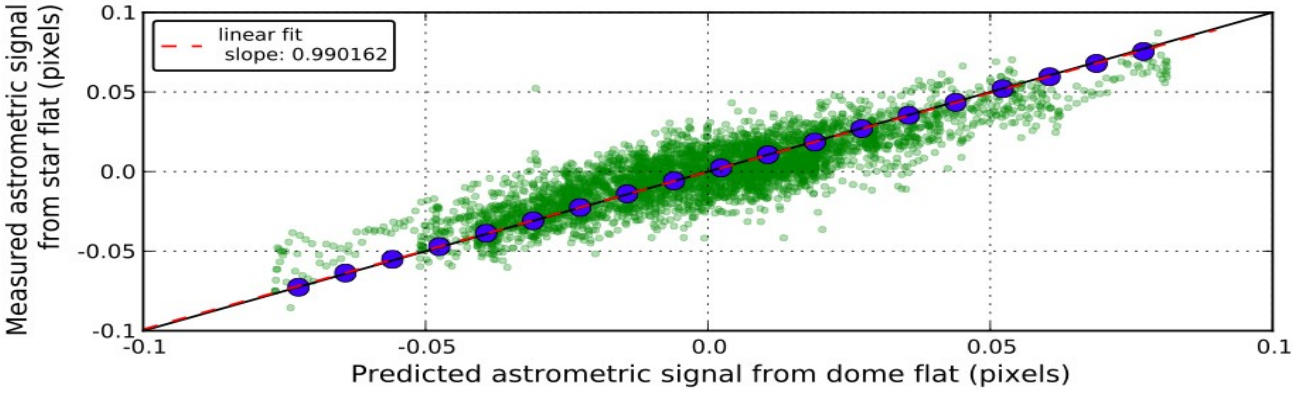
- All CCDs show approx 0.5% larger PSF for bright stars than faint ones.

Andres Plazas: Tree rings in DES

Developed procedure to correct astrometric bias using dome flats







Steve Holland : Physics of Fully Depleted CCDs

- Tree-rings are doping variations in silicon boules

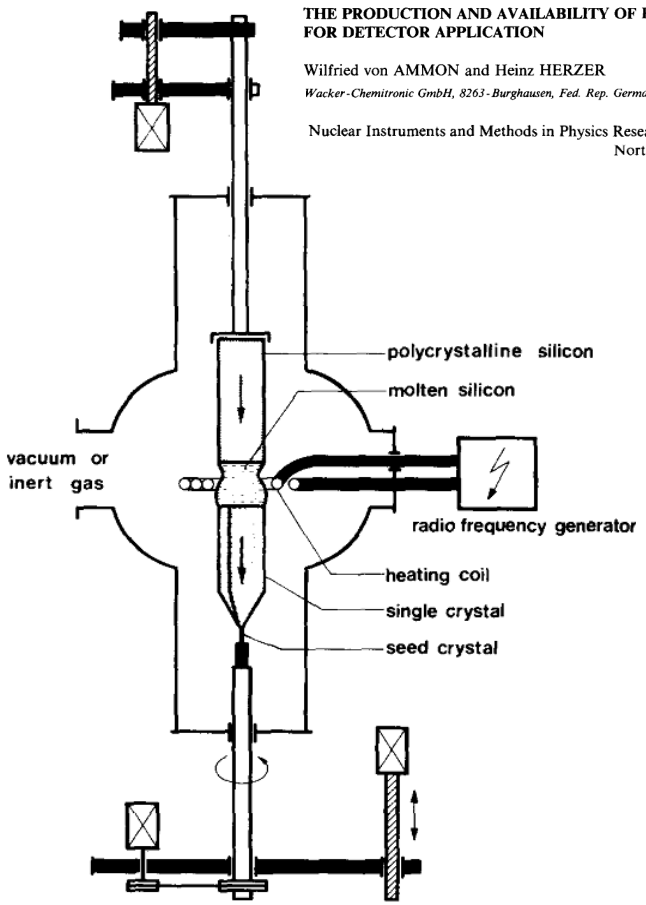


Fig. 4. Single crystal growth by the floating zone technique.

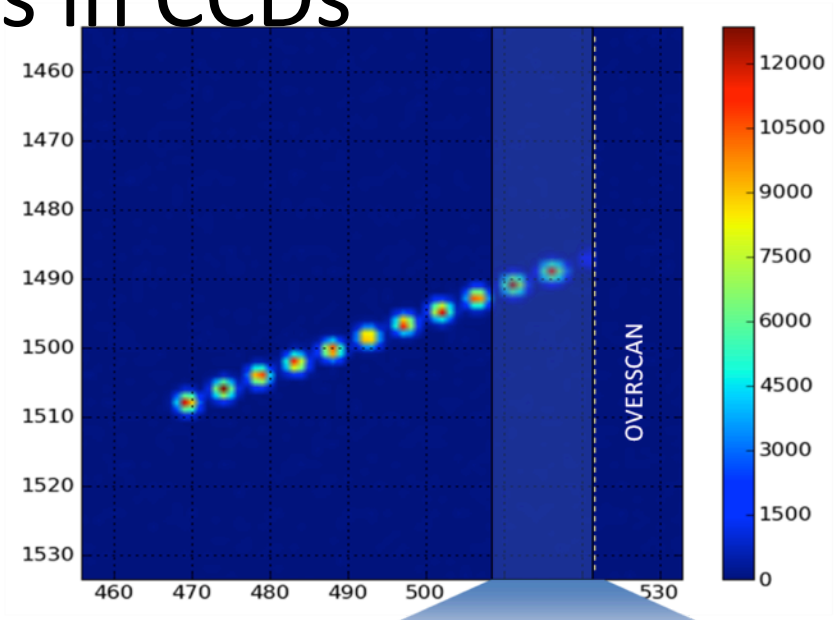
Factors affecting resistivity variations
Leif Jensen (Topsil) visit to LBNL

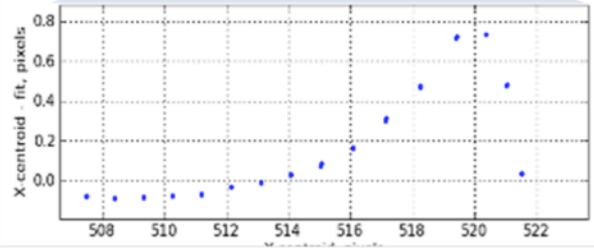
- Rotation and pull speed
- Segregation coefficient (liquid/solid)
- Boron ~ 1, Phos ~ 3
- Shape of growth surface versus final wafer
- Topsil product Uniform High Purity Silicon
  - Only produced in n-type

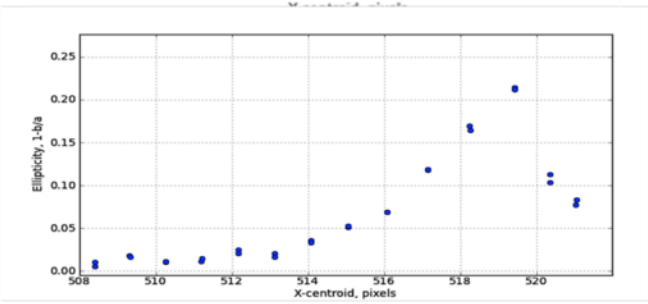
Paul O'Connor: Edge Effects in CCDs

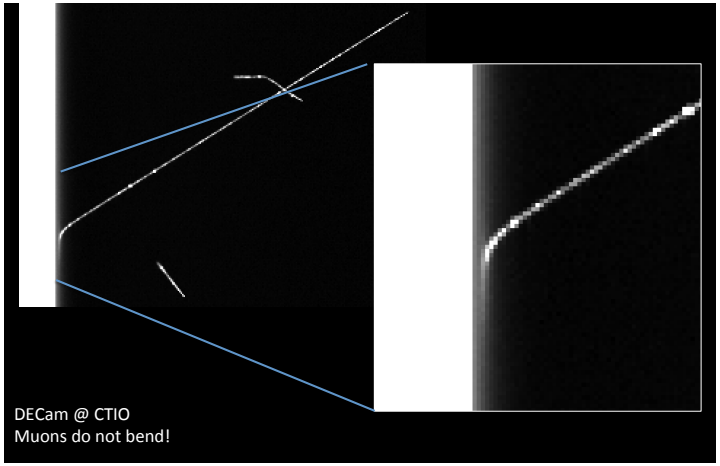
- On the egde:
  - Non-linearity up to 50%
  - Ellipticity up to 20%

- Juan Estrada: DM searches with FD CCDs - saw similar effects in DES CCDs for cosmic muons



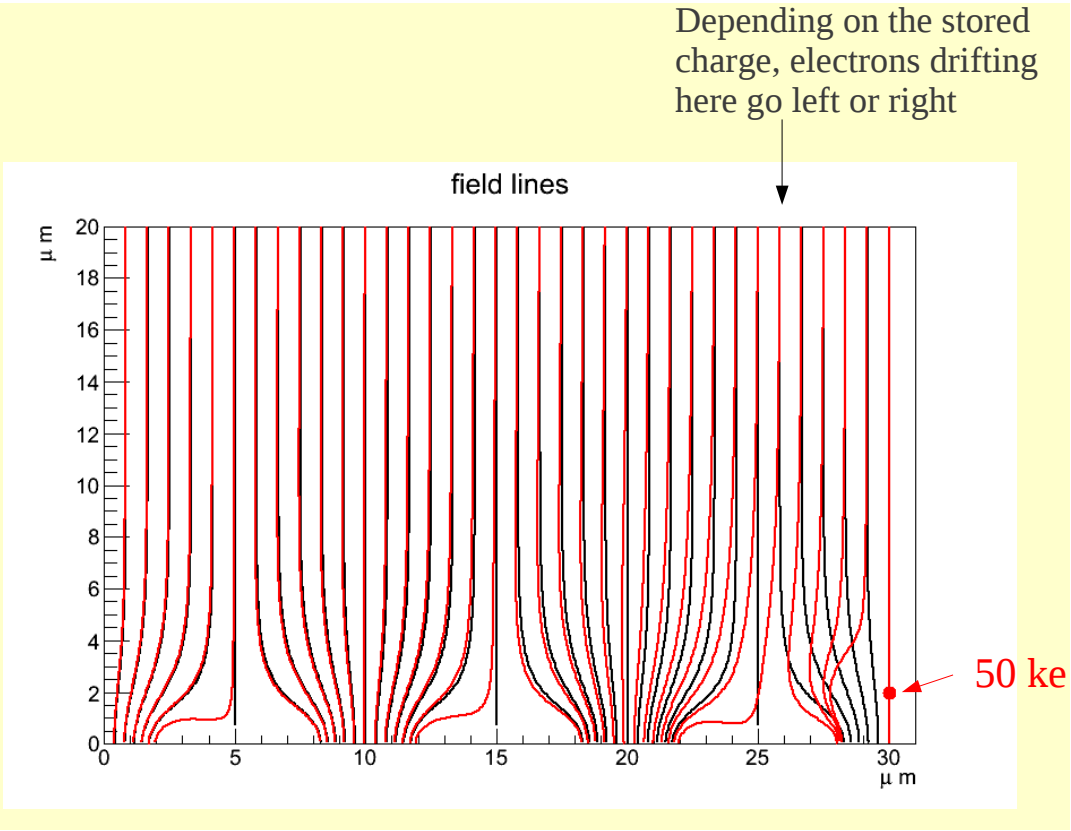


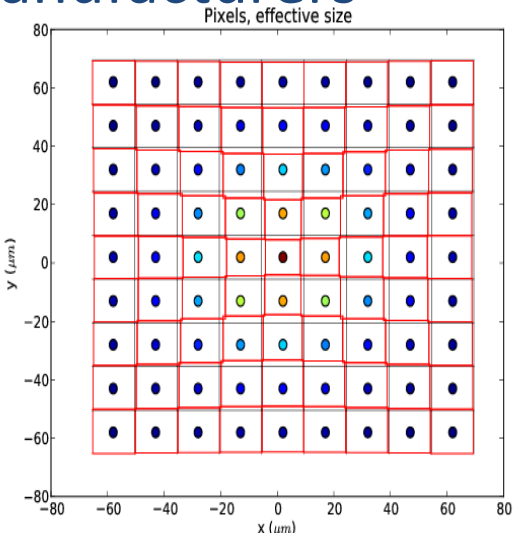


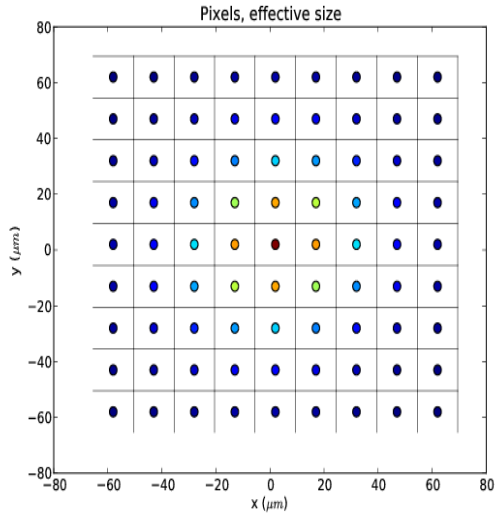


Pierre Astier: Brighter-Fatter Effect and Pixel Correlations

- Phenomenological approach, extract parameters from correlation matrices, can fit both effects reasonably well
- No need to extract secrets from CCD manufacturers



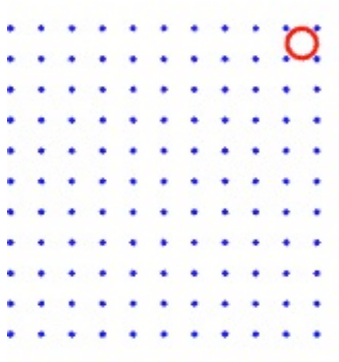


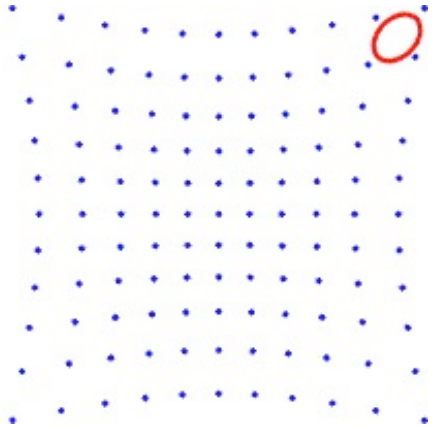


Mike Jarvis : Challenges for Precision Shape Measurements

Primer how to deal with distorted pixels in algorithms (Jacobians etc)

The World Coordinate System defines the conversion
from chip coordinates to local sky coordinates:





$$J = \begin{pmatrix} \frac{du}{dx} & \frac{du}{dy} \\ \frac{dv}{dx} & \frac{dv}{dy} \end{pmatrix} = \frac{1+\mu}{\sqrt{1-g^2}} \begin{pmatrix} 1-g_1 & -g_2 \\ -g_2 & 1+g_1 \end{pmatrix} \begin{pmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{pmatrix}$$

Robert Lupton: What's a WCS?

When most astronomers hear the acronym WCS they think, ``Ughh. Calabretta and Greisen. FITS". They should think

```
wcs = data.getWcs()
print wcs.pixelToSky(afwGeom.PointD(10, 100))
```

In other words, that astrometry is a mapping from the pixel coordinates to the sky

Robert Lupton & Mike Jarvis' talks in Jim Gunn's interpretation

Images and Image Processing

Observed x,y image in CCD
---> u,v image `on' silicon (electrostatics, ??)
---> α, δ image on sky (optics, atmosphere)

all affected by filter response, QE, SED, brightness and SB distribution of sources

Paradigm of CCD images being perfect representations is (already was) clearly broken.

Need to keep at least

1. Signal (pixel flux)
2. Location of pixel
3. Size and shape of pixel (need Jacobian MATRIX, not just determinant.

Scale? Separable large-scale and small-scale effects?
Or just bite the bullet?
Effects ARE small, and probably we do not need exact treatment.
Task is to find algorithmically practical solutions.

Erin Sheldon & Josh Meyer

Science

Erin reminded us that the MEASUREMENT of shear, even with perfect images, is not a solved problem

Depends on excellent statistical understanding of the shapes of galaxy images. Forward modeling is subject to model bias, and this is likely to be dominant.

Josh Meyer and Pat remind us that these shapes and their measurable properties depend on wavelength, and the observed images depend on details of the galaxy SED, and these chromatic effects are almost certainly large enough to be a large or dominant effect with real images. No color gradients yet, but MAY not be important.

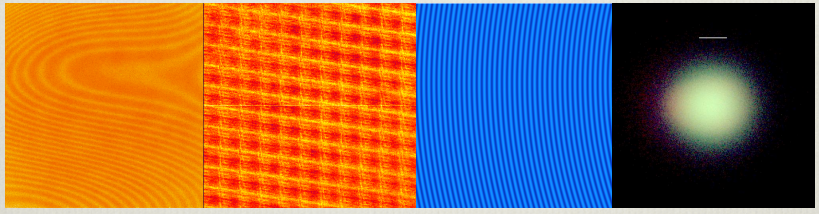
Nothing, really, to do with CCDs, but these problems need to be solved independently even with perfect CCDs.

John Peterson: Simulating Telescopes One Photon at a time

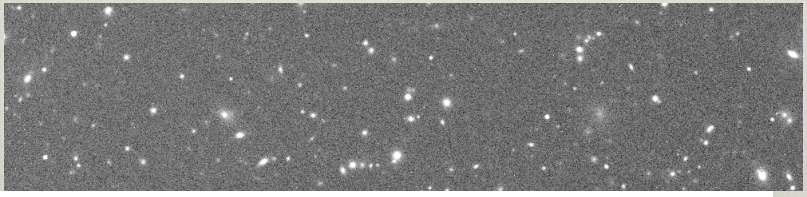
Connecting Sensors to Precision Astrophysics

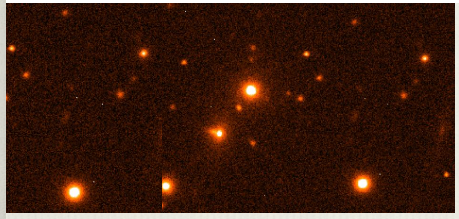
- Two major ways to use PhoSim for the topic of this meeting:

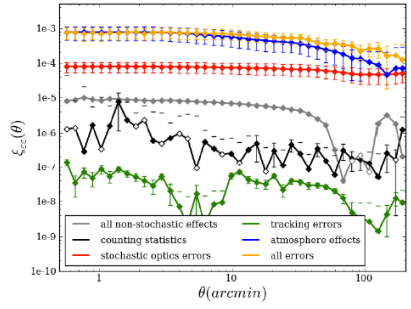
1) Simulate sensor laboratory data to validate phosim & our understanding of the devices



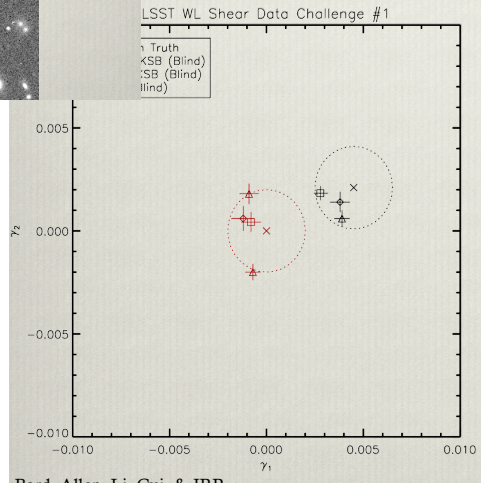
2) Simulate real astronomical scenes and run algorithms to determine systematics (can turn physics on/off)



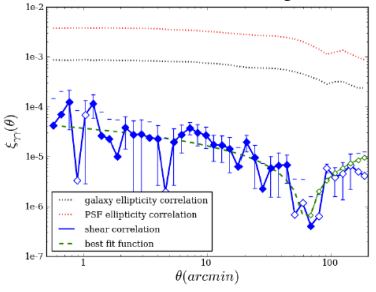




Chang et al. 2012



Bard, Allen, Li, Cui, & JRP



Science Applications

Blind shear survey with 10 sq. degrees
Estimated shear systematic floor
Need to do this for each detector effect
Wide spread use is just beginning

Many other interesting talks & posters

- Studies of sensor effects in the lab (Ivan Kotov, Kirk Gilmore, Chaz Shapiro)
- Other sensor features (Andy Rasmussen - tearing, Roger Smith – variable pixel size)
- DES calibration issues (William Wester)
- Fully depleted CCDs for spectroscopy – BOSS (Julien Guy)
- ....

Jim Gunn : Summary (1)

The Way Forward

Effects are understood *semi*-quantitatively.
Interesting and encouraging that we have learned so much from astronomical data

BUT

Surely better to learn under controlled conditions in the lab.
Still some real question about how to do these experiments.

Jim Gunn : Summary (2)

Challenges

Chris urged us to larn to speak the same language, and to be a bit precise (glowing edge, indeed !!!)

Most of what we have discussed is `just' electrostatics, but the source of the fields is very varied

Need classification and agreement about what we are talking about, and discussion needs to cross fabrication, electronics, testing, astronomy, simulation, software

But most of all, need work in all these sectors to understand the detectors as well as possible at EACH stage, but especially before they reach the telescope.

Workshop was a big success, achieved its goals

Next:

- Publish proceedings
- Maintain communications between experiments, form a working group to discuss sensor effects in simulations, algorithms and science
- Organize another workshop in a year